EXPERIMENTAL OBSERVATION OF STIMULATED COMPTON ABSORPTION OF LASER RADIATION IN A SPARK

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It has been pointed out recently in a number of theoretical papers that stimulated Compton scattering can play a noticeable role in the absorption of sufficiently intense electromagnetic radiation by a plasma. As is well known, ordinary bremsstrahlung absorption decreases rapidly with increasing plasma temperature and is proportional to the square of the electron concentration in the plasma. At the same time, according to the theory, stimulated Compton scattering should depend relatively little on the electron temperature and is proportional to the first power of the concentration. Consequently, under definite conditions, the absorption mechanism in question may play a significant role in the process of heating of a high-temperature plasma with the aid of intense laser radiation.

We report here the first experiments on the observation of stimulated Compton scattering (SCS) of laser radiation in a plasma. The measurement procedure is based on the fact that in the SCS process the total number of emission quanta remains unchanged, and the transfer of energy from the radiation to the electrons of the plasma is the result of the change of the frequency of the scattered quanta. Consequently, the spectrum of the scattered radiation, i.e., the radiation passing through the plasma, should differ in the SCS case from the spectrum of the incident radiation in that the long-wave side is deformed. It is difficult to explain such a deformation of the spectrum by interaction between radiation and a plasma as being due to other causes.

The experimental setup is shown in Fig. 1. A picosecond radiation pulse from a ruby laser 1 passes through an optical amplifier 2 and strikes the input lens of chamber 3. This part of the setup has already been described in detail earlier [4]. Control measurements of the laser pulses were made with the aid of a calibrated system consisting of photocell 4 and broadband oscilloscope 5. The laser pulse duration, measured with the aid of a high-speed photochronograph, was 50 psec.

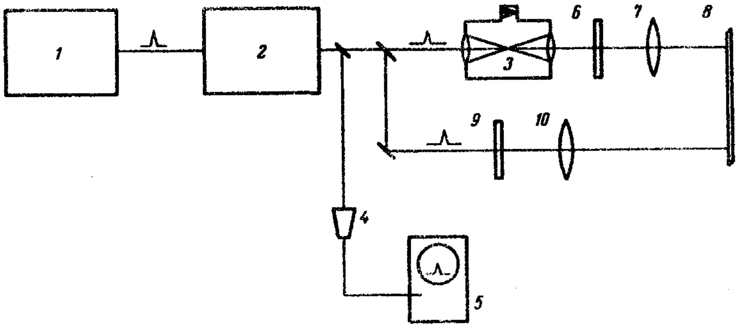

Fig. 1. Diagram of experimental setup: 1) laser, 2) optical amplifier, 3) chamber; 4) photocell, 5) high-speed oscilloscope, 6,9) attenuating filters, 7, 10) collimating lenses, 8) entrance slit of spectrograph.

The flux density at the focus of a lens with f = 2 cm was 2×10^{14} W/cm^2, which is much higher than the threshold density for breakdown and for the production of a spark in gaseous helium. The radiation pulse passing through the plasma produced by it was collimated by lens 7 on the upper half of the input slit of spectrograph 8. At the same time, part of the radiation, without passing through the chamber, was projected on the lower half of the input slit of the spectrograph with the aid of a lens 10. Such a scheme ensured comparison of the spectrum of the radiation passing through the plasma with the reference spectrum of the laser radiation in each measurement. To measure

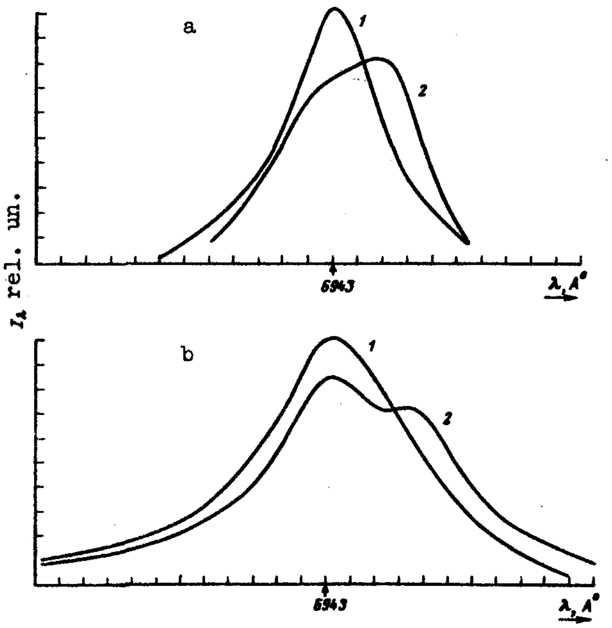

Fig. 2. Experimental forms of the spectra of the reference laser radiation (1) and of the radiation passing through the plasma (2): a) helium plasma, b) aluminum foil. Each division on the wavelength scale is equal to 0.12 Å. The measurement errors are given in the text.

the relative positions of these spectra, we photographed simultaneously the arc spectrum of iron. The spectrograph has a linear dispersion of 12 cm^{-1}/mm and an apparatus function 0.18 cm^{-1} in the investigated region. The error in the determination of the relative shift of the spectra did not exceed 0.1 cm^{-1}.

The results of the experiment with the helium plasma at an initial gas pressure of 3 atm are shown in Fig. 2a. Curve 1 is the spectrum of the reference radiation, and curve 2 the spectrum of the radiation passing through the plasma. We see that the short-wave components of the radiation spectrum are absorbed and the long-wave components are intensified. At a plasma length $\ell = 5 \times 10^{-3}$ cm, the maximum absorption coefficient of the spectral component amounts to $\alpha_\nu = 24$ cm^{-1}. The redistribution of the energy spectrum of the radiation, caused by the stimulated Compton scattering, leads to absorption of part of the incident energy by the plasma. The relative absorption integrated over the entire spectrum can be calculated from curves 1 and 2 in the following manner:

$$k = \frac{\int h\nu f_1(\nu)d\nu - \int h\nu f_2(\nu)d\nu}{\int h\nu f_1(\nu)\,d\nu},$$

where $f_1(\nu)$ and $f_2(\nu)$ are the forms of curves 1 and 2, respectively. Since the SCS in the plasma is accompanied by absorption due to the bremsstrahlung effect, curves 1 and 2 were normalized in such a way that the areas under them were equal. Such a normalization corresponds to conservation of the total number of photons in the SCS. In the case of a helium plasma we obtain for k the value $k = (1.3 \times 0.3) \times 10^{-5}$. From this we get for the coefficient $\alpha = k/\ell$ of absorption of the incident radiation by the plasma the value $\alpha = 0.26 \times 10^{-2}$ cm^{-1}.

Similar results (Fig. 2b) were obtained in an experiment in which an aluminum foil about 150 Å thick, on a lavsan polyester base 4×10^{-4} cm thick, was placed in the chamber near the focus of the lens. Just as in the case of the helium plasma, a deformation of the spectrum towards the longer wavelengths is observed, as well as an additional maximum, shifted by (0.8 ± 0.1) cm^{-1}. The line broadening amounts to (0.4 ± 0.1) cm^{-1}. Calculations by the indicated method yield for the relative absorption $k = (1.9 \pm 0.3) \times 10^{-5}$. The coefficient of absorption of the incident radiation by the plasma is in this case equal to 2×10^{-2} cm^{-1}. A quantitative comparison of the measured quantities with those calculated on the basis of the equations in [1] is difficult, since not all the necessary parameters are known from the experiment. Estimates show that α_{theor} exceeds somewhat the measured values of α.

The aggregate of the experimental data and of the conditions under which they were obtained indicates that the observed shift of the radiation spectrum towards longer wavelengths is connected with the effect of stimulated Compton scattering. It should be noted that a similar effect could result from such mechanisms as stimulated scattering in a nonisothermal plasma, owing to collective effects, and the time variation of the refractive index in the focal region, owing to excitation of the atoms or molecules and to electrostriction. However, a comparison of characteristic times of development and duration of the laser pulse shows that these mechanisms cannot make a noticeable contribution to the observed effect.

The foregoing experimental observation of stimulated Compton absorption in a plasma confirms the theoretical assumption [1 - 3] that this effect can play an important role in the heating of a plasma by electromagnetic radiation. If the radiation intensity is high enough, then at low plasma densities and at high temperatures the SCS may prevail over the classical and bremsstrahlung absorption, which furthermore are reduced by the nonlinear effects in a strong field [5, 6]. However, the physical nature of this type of absorption gives grounds for hoping to obtain a sufficiently effective contribution of the radiation energy to the plasma, provided only the width of the emission spectrum $\Delta\nu$ is comparable with the emission frequency ν [3]. This raises the problem of producing special high-power sources of coherent radiation.

Our experimental results do not agree with the hypothesis in [1] that the electron-heating mechanism in question can play an important role during the development stage of breakdown at optical frequencies. In particular, the estimate of the magnitude of this effect under the conditions of experiments on breakdown by picosecond pulses [7] shows that it is not decisive in the production of the laser spark.

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PARTICLE PRODUCTION IN COSMOLOGY

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According to rough semiquantitative estimates, the production of elementary particles near a singularity in an anisotropic cosmological model is capable of resulting in an energy density sufficient for isotropization of the expansion. If the aforementioned estimates are correct then, when account is taken of particle production, the power-law asymptotic form of a singularity of the Kasner type turns out to be internally contradictory as applied to cosmology, and all that can remain is the degenerate case of a fictitious singularity with exponents 1, 0, and 0 or an isotropic Friedmann singularity. Particle production may turn out to be of importance for the explanation of the presently observed ratio of the total number of particles (mainly photons) to the number of baryons.